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A Study of Effects of Visual Flicker and Auditory Flutter on Human Performance

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University of Oklahoma

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AIR FORCE ARMAMENT LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
EGLIN AIR FORCE BASE, FLORIDA

A STUDY OF EFFECTS OF VISUAL FLICKER AND AUDITORY FLUTTER

ON HUMAN PERFORMANCE

A. E. Dahlke
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FOREWORD

This research and development program, conducted under contract AF 08(635)-5256, entitled "A Study of Effects of Visual Flicker and Auditory Flutter on Human Performance", was carried out by the Systems Research Center of the University of Oklahoma Research Institute. The period of the contract was nine months, from June 26, 1965, through March 26, 1966. The experiments were conducted in the Psychological Weapons Research Facility, Air Force Armament Laboratory (ATCB), Research and Technology Division, Air Force Systems Command, Eglin Air Force Base, Florida.

The project was under the direction of A. E. Dahlke, Ph.D. and J. D. Palmer, Ph.D., co-principal investigators. Persons contributing to this program and deserving a high degree of recognition include:

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Finally, it is a great pleasure to acknowledge the technical assistance given by Miss Jo Ann Haferkamp, Mrs. Eloise Oviatt, and Mrs. Mary Lee Gibson for various periods during the life of the project.

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Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

NICHOLAS H. COX, Colonel, USAF
Chief, Bio-Chemical Division

ABSTRACT

Results of nine laboratory experiments conducted under contract AF 08(635)-5256, entitled "Study of Effects of Visual Flicker and Auditory Flutter on Human Performance", are contained in this report. The purpose of the research was to assess the feasibility of using dual source flickering lights and fluttering tones as harassment devices or as non-lethal weapons. Performance was measured on depth perception, manual dexterity, aiming and tracking, vigilance and a cognitive-motor task. Psychophysical judgments of the apparent movement effect produced by two lights flickering out of phase were obtained in one experiment. Postexperimental interviews were given to assess the psychological and somatic symptoms associated with exposure to flicker and flutter.

While dual source flickering lights produce performance decrement from optimum conditions, they are no more effective than a single light. Compared to performance under artificial moonlight flickering lights do not add to performance decrement. A few minor psychological and somatic complaints under flicker were reported. These were neither serious enough nor wide spread enough to justify the use of flickering light as a weapon. Little quantitative data was obtained with regard to fluttering tones, however, informal observation led to the conclusion that flutter did not show promise as a harassment device at the intensities investigated.

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SECTION I

INTRODUCTION

A series of laboratory psychological experiments were conducted for the purpose of identifying important variables related to specific visual and auditory stimulus situations and their effects on the human response system.

The visual stimuli investigated were produced by two high intensity strobe lights, spaced apart, which flashed alternately 180° out of phase. Employment of the lights in this manner produces an apparent movement phenomenon at frequencies below the critical flicker fusion frequency. That is, three-dimensional objects in an environment illuminated by such flickering lights appear to move back and forth. The phenomenon is produced by the alternating angle of illumination on the three-dimensional object and the resulting shadow shift. Within the range of about 4-16 alternating flashes per second the human visual system does not perceive the shadows as shifting but rather perceives the object itself as repetitively moving from side to side. This is similar in principle to the classic "Phi" phenomenon.

The purpose of the present research was to investigate the possibility of using visual flicker as a harassment device or a psychological weapons tactic. Preliminary (non-experimental) observations had suggested that the unstable visual field produced by such flickering lights might severely limit human performance capacities, be psychologically stressful and produce somatic symptoms such as dizziness and nausea.

During the course of the investigation, another kind of flicker phenomenon was discovered which did not produce as much apparent movement as that described above but which also seemed to have disrupting effects. This effect was produced by allowing the individual strobe lights to flash more than once before alternating to the second light. It seemed that this kind of flicker might be more disruptive of the visual field, particularly at slow flicker frequencies. Accordingly, the latter experiments in the series include investigations comparing this second kind of flicker to the first at various frequencies.

The strobe lights used were the type ordinarily used at close ranges in conjunction with the Grass Electroencephalograph (Model 6-A) for the detection of epilepsy. They were regulated as to individual intensity and flicker frequency by a device manufactured by the Grass Company that allowed five settings representing approximately successive doubling of the light intensity at the peak of 10 ms flash measured two feet from the bulb: (1) 62,500 candle power, (2) 125,000 candle power, (3) 375,000 candle power, (4) 750,000 candle power, and (5) 1,500,000 candle power. These settings are coded on the Grass instrument as 1, 2, 4, 8, and 16, respectively. Since the lights were always used at a range of 10 or more feet from the visual target the actual light intensities were much less and difficult to actually measure. Consequently, the manipulations of intensity in this report will be referred to in terms of the settings on the Grass device. As these lights were employed in pairs, a special device was built which regulated the overall flash frequency and phase relationships of both lights combined.

The sound used in these experiments was generated by two Hewlett-Packard oscillators which could be adjusted throughout the audible range of frequencies. A special electronic device was built and connected between the oscillators and the amplifiers so that the flutter effect (rapid on-off) could be produced. Difficulties with the sound equipment precluded the collection of a large amount of data using fluttering sounds. The bulk of the results here reported are concerned with the effects of visual flicker.

The experiments were conducted at Eglin Air Force Base, Florida, at the Psychological Weapons Research Facility, Advanced Technology Branch. The experimental room was 23 feet 6 inches long and 16 feet 9 inches wide. It had an 8 foot ceiling. The room was scund proofed and it was painted flat black to eliminate glare in the light experiments. A control room 23 feet 6 inches X 8 feet wide adjoined the experimental room. Communications between these two rooms was by an intercom and a closed circuit television system.

Since the present investigators have elsewhere reported the results of research involving the effects of multiple flickering light sources which included a review of past literature (see Investigation of Psychological Effects of Non-Nuclear Weapons for Limited War, Vol. II, AF 08(635)-3693, Directorate of Armament Development, Research and Technology Division, Air Force Systems Command, Eglin, AFB, Florida. Technical Report No. ATL-TR-65-39, Jan. 1965), a review of past literature is not included in the present report. The research reported in the above referenced study is the only known experimentation on the effects of two lights flickering out of phase on performance. Considerable research has been done on the effects of a single flickering light source. The general conclusion of these reports is that flickering light leads to performance decrement.

The general plan of the research program was to begin with the manipulation of the stimulus variables such as frequency, intensity and position and to assess performance on a number of different tasks or dependent variables. The plan was to obtain subjective reports of the effects of flicker and flutter during the performance tests. Assuming that the optimum stimulus variables could be identified it was then planned to investigate these optimum conditions with some ambient light present, and finally to investigate the effects of longer term exposures to the stimuli.

The subject population was composed of both males and females, with a predominance of males. Both military and civilian personnel were tested. All military personnel were required to spend approximately one hour in psychiatric screening at the Eglin AFB Hospital before participating in the experiments. All subjects were volunteers. The age range was from 18-40 years.

SECTION II

EXPERIMENTS

EXPERIMENT ONE

DEPTH PERCEPTION UNDER DOUBLE FLICKERING LIGHTS AS A FUNCTION OF FLICKER FREQUENCY, LIGHT POSITION AND INTENSITY

Since past studies on flickering light have generally reported detrimental effects on various behavioral performance indices (See Vol. II of Investigation of Psychological Effects of Non-Nuclear Weapons for Limited War, AF 08(635)-3693, No. ATL-TR-65-39, Directorate of Armament Development, Research and Technology Division, Eglin AFB, Florida,) the following study was undertaken. As noted in the review of the literature in the above mentioned reference, generally only one flickering light source has been employed. On the assumption that multiple flickering light sources would cause an added increase of interference in performance, this study was concerned in evaluating the effects of two flickering lights on perceptual-depth performance.

It was deemed necessary to investigate a number of factors associated with the flickering lights, such as the frequency, intensity, and position.

METHOD

Eighteen subjects performed a depth perception task under combinations of three flicker frequencies (6, 9 and 12 cps, or total flashes per second) and three intensities (2, 8, 16 settings on the Grass Photo Stimulators), making a total of 9 stimulus combinations. These stimulus combinations were repeated under two light positions (toward and away).

Subjects run individually were seated behind a large black shield, having a viewing port which could be closed by a sliding door, located 4 feet from one wall of the experimental room. Two 6 foot metal poles (3/4 inch in diameter) which were mounted vertically 6 inches apart on a wooden base were placed 14 feet from the viewing port. One of these poles was moveable by means of cords given to the subject behind the shield. The viewing port was closed between trials so that the subject could not observe the experimenter recording the judgmental error and resetting the poles.

In the toward light position the lights, mounted on 5 foot stands, were placed across the length of the room from the subject and in opposite corners from one another. Thus, they formed a 110° angle in relation to the depth perception poles and each light was approximately 8 1/2 feet from the poles. In this condition the flash of the light sources was in view of the subject. In the away light position the lights were in each corner on the same end of the room as the subject and slightly behind him. Thus, they formed a 90° angle in relation to the depth perception poles which were at a distance of 16 feet.

Each subject made a total of 30 depth perception judgments. Nine judgments (one for each of the frequency-intensity combinations) were made under each of the toward and away light positions. Six control trials, under

normal room lighting, were given before exposure to flicker and 6 after the 18 flicker trials. Each subject either made all of his toward or all of his away judgments first before light positions were changed. This order was counterbalanced between subjects, as were the frequency and intensity combinations.

The moveable pole on the depth perception apparatus was set randomly on each side of the stationary pole and randomized within subjects, with the one condition that each subject receive an equal amount of away and toward pole settings.

The following instructions were given:

> Please be seated on the chair behind that shield. We are going to test your depth perception under several different flickering light conditions, as well as under the regular room lighting. Adjust your chair so that you can comfortably look through the viewing port. Notice on the far end of the room the point where the baseboard and rug come together. Line this up, that is, sight it, so that you can just see the baseboard along the lower edge of this viewing port (pointing). From this position you should not be able to see either the top of the poles or the platform on which they stand. Is that correct? This is the position that I want you to come to every time you make a depth perception judgment. When you are not making a judgment you may sit back and relax in your chair. Here's the way we will go through the depth perception judgments: I will close this port and set the adjustable pole so that it is either behind or in front of the stationary one. Your task is to pull the adjustable pole either forward or backward until it is just even with the stationary one. Once you have determined the direction it needs to go pull the pole with the strings until it appears to be parallel with the other one, you may not adjust back and forth (demonstrating) just pull until they are equal and then stop. Are there any questions?

At this point the experimenter opened the port of the shield and manipulated the strings to demonstrate to the subject exactly how he was to go about making his depth perception judgments.

The subject was first given 6 control trials, and then the overhead lights were turned out and the room remained dark between flickering light trials, except that the experimenter used a flashlight to record the subject's judgments. Between the "toward" and "away" trials, i.e., when the light position was changed in the room, the overhead lights were turned on for approximately one minute, then turned off again and the other sequence of flashing light trials were given. At the end of this sequence the subject was again given 6 control trials.

RESULTS

Scores were recorded in quarter-inch deviations from the stationary

pole. Table 1 depicts the mean deviation error scores for 18 subjects under 3 levels of intensity and flicker frequency, and 2 levels of light position, and under control conditions.

The corresponding analysis (a 3 x 3 x 2 with 18 replications considered as a random variable) is presented in Table 2.

The analysis of the first 6 practice trials vs the last 6 trials under normal room light yielded an F ratio of .006 which was not significant. However, comparing the 12 control trials to the experimental trials gave an F ratio of 15.35 ($p < .01$) with less judgment error occurring under the control condition.

The effect of light position on subsequent judgment yielded an F ratio of 6.49 which was significant beyond the .05 level. The average judgmental error in the "away" position (lights positioned back of the subject focused on the poles) was 3.96 units (.99 of one-inch error) and for the "toward" position (lights flashing from an angle toward the target and subject) was 5.61 units (1.40 inches error).

The Frequency variable yielded an F ratio of 3.60 significant beyond the .05 level. Average error scores under the three different frequency levels of 6, 9, and 12 flashes per second were 5.14 (1.29 inches), 5.21 (1.30 inches and 4.01 units (1.00 inch) respectively. Examination by orthogonal contrasts indicated a significant difference at the .05 level comparing 6 and 9 flashes per second vs 12 flashes per second. The performance error at 12 flashes per second was 4.01 units (1.00 inch) compared to 5.18 units (1.30 inches) for the 6 and 9 flicker frequencies combined. The orthogonal contrast between 6 flashes per second and 9 flashes per second, however, was not significant.

The Intensity variable (2, 8, or 16 brightness) approached significance ($p < .10$) in the overall analysis. Orthogonal contrasts comparing the intensity levels of 2 and 8 vs 16 was not significant while the contrast of 2 vs 8 approached significance ($< .10$) with less judgmental error occurring at the higher intensity. None of the 2-way or 3-way interactions were significant.

DISCUSSION

The findings from this experiment indicate that the main effects of the position of the lights and flicker frequency contributed significantly to the depth perception judgments. The best performance (least judgmental error) occurred under the conditions of the lights positioned away from the subjects focused on the task. The intensity was set at level 16 on the Grass photo stimulator with 12 flashes per second (6 per light). This would appear to be the logical result as under these conditions more light was present, permitting the subject to utilize more cues in his judgment. The lights in the away position (focused on the poles from an angle behind the subject) would cause less interference with visual processes than in the toward condition in which the lights would be flashing more directly toward the subject. With regard to intensity level, the best performance occurred at an

TABLE I

AVERAGE ERROR ([illegible] QUARTER-INCHES) IN DEPTH PERCEPTION TASK
UNDER [illegible]BLE FLICKERING LIGHT

Away Light Position

Light Intensity (Instrument Settings)	Frequency (Cycles per Second)			Row Averages
	6	9	12	
2	6.50	4.39	3.00	4.63
8	4.22	4.39	2.89	3.83
16	3.67	3.83	2.78	3.43
Column Averages	4.80	4.20	2.89	3.74

Toward Light Position

Light Intensity (Instrument Settings)	Frequency (Cycles per Second)			Row Averages
	6	9	12	
2	4.94	7.33	5.83	6.03
8	5.56	5.28	4.89	5.24
16	5.94	6.06	4.67	5.56
Column Averages	5.48	6.22	5.13	5.61

Control - No Flicker

Prior to Treatment	After Treatment
3.51	3.19

Combined

3.35

TABLE II

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE I

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F Ratios	Probability
Intensity	2	48.46	24.23	2.75	< .10
Frequency	2	98.29	49.15	3.60	< .05
Position	1	220.02	220.02	6.49	< .05
Replication	17	1630.97			
Intensity x Frequency	4	2.41	.60	.03	NS
Intensity x Position	2	9.39	4.69	.58	NS
Intensity x Replication	34	299.54	8.81		
Frequency x Position	2	38.23	19.12	1.31	NS
Frequency x Replication	34	463.71	13.64		
Position x Replication	17	573.09	33.89		
Three-way Interaction	4	86.78	21.70	1.20	NS
<u>Error Terms</u>					
IF(R)	68	770.92	11.34		
FP(R)	34	494.66	14.55		
IP(R)	34	274.83	8.08		
IFP(R)	68	1223.00	17.98		

intensity level of 16. With a decrease in intensity level, there was also a decrease in performance, although this difference was only significant at the .10 level of confidence.

Since this study is concerned with determining the variables which will lead to the greatest decrement in perceptual depth performance, we will now look at the poorest performance. Under the conditions of 2 intensity and 9 flashes per second with the lights positioned at an angle toward the subject, the greatest amount of judgmental errors occurred. The mean under this condition was 7.33 which is 1.83 inches of judgmental error. The next poorest performance occurred also in the light toward position with the intensity level at 16 and the frequency at 9.

With regard to the Frequency variable, it is interesting to note that the largest error in judgment occurred in the toward condition with a setting of 2 intensity and 9 frequency, (see Table 1). Previous studies have reported that a frequency of 9 is usually the most disturbing and produces the greatest performance decrement. However, the difference between 9 and 6 cps in the present study was not statistically significant.

EXPERIMENT TWO

MANUAL DEXTERITY UNDER DOUBLE FLICKERING LIGHTS

This experiment represents an attempt to evaluate the effects of two lights flickering out of phase on a manual dexterity task. The double flickering lights spaced apart produce an apparent movement of objects in the environment. It was expected that this effect would be extremely disruptive to performance requiring hand-eye coordination in the manipulation of small objects. The experiment was designed to assess the effects of flicker frequency and light intensity on manual dexterity.

METHOD

This experiment was run concurrently with Experiments One and Three using the same 18 subjects. The order of experiments was counterbalanced between subjects, and rest periods were given between experiments.

The experimental task was the "pins and collars" task of the Crawford Small Parts Manual Dexterity Test. In this task subjects are required to pick up a small pin from a shallow bin with tweezers and to place it in a hole in a metal board. Then the subject picks up a small collar from another bin and places it over the pin which is protruding from the board. The dependent measure was the number of pins and collars that the subject could correctly place on the board in three minutes.

The experimental design compared combinations of three frequencies (6, 9 and 12 cps) and three light intensities (2, 8 and 16 settings on the Grass Photic Stimulators). Each subject performed the task two times. First under a control condition of regular room lighting and second under one of the 9 experimental conditions. Between the control and experimental trial, a three minute rest period was given. For each stimulus combination there were two replications, making a total of 18 subjects.

The lights were placed in a "toward" position (flashing into the subjects' eyes as well as on the task). They were approximately 150° apart, set on opposite sides of the experimental room which was 16 feet, 9 inches wide; and to the front of the subject. The distance from each light source to the subject's task was approximately 12 feet.

The following instructions were given:

> "This is a test of ability to use your hands to put together small parts. It is a test that was developed for use in industry for screening job applicants for such tasks as putting together small electronic parts, etc. We are merely using this task as a performance measure in the flickering light experiment. Here is the way you do it: You take this set of tweezers and hold them in your hand whichever way is combortable for you. First you pick up one of these little pins like this (demonstrating) and

place it into one of these holes like this. Then you pick up one of these collars from the other bin and place it over the pin that you have already placed on the pegboard making sure that the flange part is down (demonstrating). Now, why don't you do the rest of this row for practice before we start timing you".

After completing the practice row the subject was timed for three minutes under regular light. The number of pins and collars placed were counted, and a three minute rest period was given. Then the subject repeated the task under one of the 9 combinations of frequency and intensity.

RESULTS

Difference scores were obtained between each subject's performance under regular and flickering light. These scores were then used in the analysis. All scores were positive indicating consistent decrement in performance under flicker. The mean difference scores for each of the 9 stimulus combinations are presented in Table 3. The corresponding analysis of variance is presented in Table 4.

It may be seen that there is a considerable range of mean difference scores from 17.5 in the 6 frequency - 2 intensity combination to 9 in the 12 frequency - 16 intensity combination. However, none of the main effects in the analysis reaches significance in the analysis of variance. A contrast between the lowest intensity and the other two does approach statistical significance ($F = 3.14$, $p < .15$). This overall lack of significance is probably due mostly to the inadequacy of the sample size for this type of design.

The most basic question to be asked of the data in this experiment is whether flicker makes a difference in performance. This question cannot be answered from the above analysis. To assess the effect of flicker disregarding the various frequency and intensity combinations a t test for dependent measures was computed between the control and experimental trials. A highly significant difference ($t - 11.62$, $df = 16$, $p < .001$) was found, indicating that flicker produces a large performance decrement on a manual dexterity task.

DISCUSSION

In this experiment a large decrement in performance was found between the control and flicker conditions. This decrement occurred in spite of the fact that the flicker condition was always given second and any practice effect that was present should have raised the performance on the second trial.

There is an empirical trend for performance to be worse under low frequency and low intensity. We can say with some justification that low intensity produces more performance decrement. It could reasonably be that the less light of any kind that the subject has on the target the more poorly

TABLE III

MEAN DIFFERENCE SCORES BETWEEN CONTROL AND EXPERIMENTAL PERFORMANCE FOR EACH OF NINE FREQUENCY AND INTENSITY COMBINATIONS

Frequency (Cycles per Second)	Light Intensity (Instrument Settings)			Row Averages
	2	8	16	
6	17.5	13.5	9.5	13.50
9	15.5	8.5	10.0	11.33
12	15.0	5.5	9.0	9.83
Column Averages	16.0	9.17	9.5	11.55 N = 18

TABLE IV

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE III

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F Ratios	Probability
Frequency	(2)	40.7	20.35	-	NS
Intensity	(2)	177.	88.5	1.56	NS
Interaction	(4)	33.6	8.4	-	NS
Error	(9)	501.3	56.7		
<u>Contrast</u>					
I_2 vs I_4 and I_8	(1)	177.83	177.83	3.14	$p < .15$

will he perform. If this were the case then possibly the control condition for this experiment should have been dim light such as moonlight rather than ordinary room light. It could be that any kind of light, flickering or not, would produce a performance increment rather than a decrement under such a test.

Further studies are needed to compare performance under flicker to performance in dim (moon) light conditions. In later experiments of this series an "artificial moon" was introduced into the laboratory setting for this purpose.

EXPERIMENT THREE

HAND STEADINESS UNDER DOUBLE FLICKER OF VARYING FREQUENCY AND INTENSITY

This experiment was run concurrently with Experiments One and Two using the same 18 subjects. It represents a continuation of the initial research effort to investigate the effects of flicker frequency and intensity using double lights. A hand steadiness tracking task analogus to the aiming of a gun was used in this experiment. This task represents a kind of performance that is considerably different from either of the previous two. Accordingly, its use was in harmony with the overall aim of the research project to investigate the effects of flicker on a variety of different tasks.

METHOD

Eighteen subjects performed a hand steadiness tracking task 6 times. The first, third and fifth trials were control trials under regular room lighting. The other three trials were performed under flickering light of 6, 9 and 12 cps. Each subject performed under only one intensity of either 2, 4 or 8 setting on the Grass Photic Stimulator. In other words, though there were 9 stimulus combinations each subject performed in only three, with replications being nested in frequency (each subject performed in all frequencies) and crossed with intensity. Thus there were a total of 6 observations under each stimulus combination. Order was counterbalanced between subjects.

The apparatus consisted of a light grey box approximately 24 inches tall, 24 inches wide and 6 inches deep. On one side of this box were cut two pathways, one was triangular and the other trapezoidal. The width of these pathways was 1 1/4 inches. They were lined with metal and wired so that touching the side of the opening with the 18 inch pointer (consisting of an 1/8 inch welding rod mounted on a pistol grip) resulted in the closing of a circuit. Both errors and time were recorded on a single channel Esterline Angus event recorder which was located in the control room.

The box was mounted on a 3 1/2 foot stand so that the subject could stand and aim the pointer in a manner similar to that of aiming a pistol. The apparatus was placed in the middle of the experimental room. The lights were placed on opposite sides of the room and slightly behind the subject so that they illuminated the task but did not shine in the subject's eyes. This positioning was comparable to the "away" condition in the depth perception experiments.

A trial consisted of 10 counterclockwise revolutions with the pointer inserted in the trapezoidal slot. The triangular slot was only used on a practice trial given before the six measured trials using the trapezoid. Subjects were seated between trials and given a two minute rest.

The following instructions were given:

"This is a test of hand steadiness. The object is to take this pointer and insert it into this slot about two inches and then trace around in a counterclockwise direction as quickly as you can without hitting the edges (demonstrating). There will be several trials under different light conditions. A trial consists of 10 revolutions around this trapezoid (pointing), without stopping. In the other room we have a timer and a counter so that we can measure how long it takes you to make 10 revolutions and also count the times you hit the sides. You are to go as fast as you can and touch the sides as few times as possible. For each trial insert the pointer here (demonstrating) at the upper left hand corner and each time you cross that point count aloud until you have completed 10 revolutions. Are there any questions? First you get 10 revolutions practice on this triangle (pointing). When I say "go" insert the pointer into the slot of the triangle and count out 10 revolutions. "Ready, go" -- now we are ready for the first trial, when I say "go" make 10 revolutions on the trapezoid, "Ready, go".

RESULTS

The time scores were measured in terms of milimeters of recorder tape travel per trial. Frequency of errors per trial were counted directly from the recorder tapes. The data were analyzed in terms of change scores with each control trial subtracted from the experimental trial which immediately followed it. This was though to be the most reasonable way of controlling for any practice effect that might have occurred over the 6 trials. The data were then analyzed with regard to time, errors and the ratio of errors to unit time multiplied by 100.

When the change scores with regard to time were analyzed by analysis of variance none of the variables were significant. Subjects took a longer time to perform the task under flicker (indicated by the high percentage of positive valued change scores), but there were no differences between the various levels of frequency and intensity sampled. It was observed during the experiment that a subject could compensate for the effect of the flicker on his speed by continuing to move rapidly at the expense of more errors. Most subjects seemed to prefer this to slowing down in order to reduce errors. Therefore, it seemed that the number of errors and/or the ratio of errors to time were a more adequate measure of the flicker effect.

Table 5 presents the mean error change scores for the 9 treatment combinations. The corresponding analysis of variance is presented in Table 6. In this analysis frequency was highly significant ($F = 6.19$, $p < .01$). Inspection of the means in Table 5 reveals that a frequency of 6 cps produced more error than did the other two. A contrast of 6 vs 9 and 12 cps was highly significant ($F = 12.3$, $p < .001$). This contrast accounts for 99 percent of the variance. Thus, frequencies 9 and 12 produced about the same amount of performance decrement while the frequency of 6 cps produced a significantly greater decrement.

TABLE V

MEAN ERROR CHANGE SCORES FOR HAND STEADINESS UNDER DOUBLE FLICKER FOR NINE FREQUENCY AND INTENSITY COMBINATIONS

Light Intensity (Instrument Settings)	Frequency (Cycles per Second)			Row Averages
	6	9	12	
2	10.17	4.83	6.17	7.06
8	10.50	7.67	5.83	8.0
16	11.33	5.5	7.50	8.11
Column Averages	10.67	6.00	6.50	7.72

TABLE VI

SUMMARY OF ANALYSIS OF VARIANCE FOR THE DATA IN TABLE V

Source	Degrees of Freedom	Mean Squares	F Ratios	Probability
Frequency	(2)	118.17	6.19	$p < .01$
Intensity	(2)	6.05	-	NS
Interaction	(4)	6.97	-	NS
Error	(15)	35.73		
Nested Error	(30)	19.08		
Contrast				
F_6 vs $F_9 + F_{12}$	(1)	234.08	12.3	$p < .001$

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When performance was measured by the ratio of errors to unit time for the actual scores there was a highly significant difference ($F = 29.91$; df 1,15; $p < .001$) between the flicker and the control trials. It was not possible to test this effect in the change score analysis which is presented below.

The mean ratio of erros to unit time x 100 change scores are presented in Table 7. The corresponding analysis of variance is presented in Table 8. It may be seen that the frequencies differ significantly ($F = 4.48$, $p < .05$). Inspection of Table 7 reveals that the frequency of 6 cps is deviant from the other two. A contrast of 6 vs 9 and 12 cps was highly significant ($F = 8.47$, $p < .01$). This contrast accounts for 95 percent of the frequency variance. Thus, an error/time ratio analysis yields essentially the same results as an analysis based on error change scores alone.

DISCUSSION

In this experiment there were no differences in intensity. Like Experiment One there was a frequency difference. However, in the depth perception experiment performance under 12 cps was better than that under 6 and 9 cps which did not differ. In this experiment performance under 9 and 12 cps did not differ while performance under 6 cps was significantly worse. Consequently, it appears that frequency of flicker is an important variable, but that the critical frequency changes depending on the nature of the task. One thing which could possibly account for the differential findings in the two experiments could be the distance of the viewed object. In the depth perception task the subject was 14 feet from the viewed objects while in the hand steadiness task the subject was only 30 inches from the test box. However, it is more likely that the nature of the tasks themselves were responsible for the differential effects of frequency.

This experiment suggests that double flickering light seriously impares tracking behavior similar to aiming a gun. Unfortunately, this experiment was not replicated using single vs double flashing light, (see Experiments Four and Five). Consequently, we do not know whether the performance decrement obtained was greater than that which could also be obtained using a single flickering light.

Since 6 cps was clearly the most effective frequency in this experiment, it was decided to follow this lead in further experiments by sampling frequencies lower than 6 cps.

In all of these first 3 experiments subjects were formally questioned post experimentally with regard to their subjective experiences and physical symptoms under flickering light. In general, there were no serious effects reported. The most severe physical symptoms occurred in the experimenters who spent long periods under flicker. They reported eye strain and headaches. Some subjects reported initial nervousness when exposed to flicker but this was considered more a result of fear of what the flicker might do to them rather than as a result of the flicker itself. This fear could reasonably be the outcome of the extensive psychiatric screening required of subjects prior to participation. Such screening could have led them to expect some rather severe effects of the lights.

TABLE VII

MEAN ERROR/TIME X 100 CHANGE SCORES FOR HAND STEADINESS UNDER DOUBLE FLICKER FOR NINE FREQUENCY AND INTENSITY COMBINATIONS

Light Intensity (Instrument Settings)	Frequency (Cycles per Second)			Row Averages
	6	9	12	
2	43	10	23	25
8	47	38	29	38
16	52	20	34	35
Column Averages	47	23	28	33

TABLE VIII

SUMMARY OF ANALYSIS OF VARIANCE FOR DATA IN TABLE VII

Source	Degrees of Freedom	Mean Squares	F Ratios	Probability
Frequency	(2)	82.74	4.48	$p < .05$
Intensity	(2)	22.30	-	NS
Interaction	(4)	9.85	-	NS
Error	(15)	58.01		
Nested Error	(30)	18.46		
<u>Contrast</u>				
F_6 vs F_9 and F_{12}	(1)	156.48	8.47	$p < .01$

EXPERIMENT FOUR

DEPTH PERCEPTION UNDER SINGLE AND DOUBLE LIGHT CONDITIONS (at 6 and 9 cps FREQUENCY), AND TOWARD VERSUS AWAY LIGHT POSITIONS

This experiment was designed as a follow up of Experiment One. In Experiment One a significant decrement in depth perception performance was found under double flickering lights, particularly when the lights were aimed toward the subject. From Experiment One it is impossible to determine whether this performance decrement is due to the apparent movement effect produced by the double lights, or whether the decrement is produced by the on-off character of the flicker. In other words, is the decrement obtained under double lights any more severe than that which could be obtained using a single flashing light. This question has considerable practical importance as it would be much easier to use a single flashing light in a field situation.

In Experiment One the frequency of the flicker (6, 9 and 12 cps) was found to have significantly differing effects on depth perception. However, this effect was due to better performance under 12 cps. The frequencies of 6 and 9 cps did not differ. It was felt that frequencies of 12 cps or above did not merit further investigation. In the present experiment frequencies of 6 and 9 cps were further investigated under double and single flicker. This was to explore possible differences between double and single flicker at different frequencies.

Since the positioning of the light sources was the most significant variable in Experiment One, it was further explored in the present experiment.

In Experiment One performance was found to improve slightly at higher light intensities. Since high light intensities would be difficult to obtain in the field at longer ranges this was encouraging. In the present experiment light intensity was held constant at a setting of 4 on the Grass photic stimulators. This setting was half way between the two lower intensities used in the first experiment. This intensity was chosen in an attempt to eliminate any confounding of extremely bright or extremely dim intensity with the critical test between double and single flickering light.

METHOD

Sixteen subjects were tested in the same depth perception task employed in Experiment One. Each subject made a total of 14 judgments. The first three and the last three judgments were control trials under regular room lighting. The flickering light experimental trials were given under the combinations of position (toward and away), frequency (6 and 9 cps) and number of lights (single and double) making a total of 8 experimental trials. The order of presentation of experimental trials was counterbalanced between subjects to eliminate practice and/or fatigue effects.

In the double flicker conditions both lights flashed alternately at a combined rate of 6 or 9 cps. In the single flicker conditions only one light (alternating sides of the room between subjects) flashed at a rate of 6 or 9 cps.

RESULTS

Scores were again recorded in quarter-inch deviations from the stationary pole. Table 9 presents the mean error scores for 16 subjects under two light positions, two frequencies and double versus single lights. Control trial means are also reported.

Significance tests for the relevant comparisons are presented in Table 10. The difference between the first three and the last three control trials was not significant indicating that subjects did not improve with practice on this task. A comparison of the combined control trials with all experimental trials yielded an F ratio of 17.79 ($p < .01$) indicating that flickering light produced a significant decrement in depth perception.

The difference between light positions approached significance ($t = 1.53$, $p < .10$). This result is comparable to Experiment One where the toward position was found to produce more performance decrement.

No difference was found between 6 and 9 cps frequency ($t = .011$, NS). This result is also comparable to that of Experiment One where 6 and 9 cps did not differ. There was also no difference between single and double flashing lights ($t = .018$, NS), suggesting that it is not the apparent movement produced by the use of two lights, but rather the on-off effect of flicker which produces the decrement in depth perception.

DISCUSSION

The results of the second depth perception experiment generally replicate those of the first experiment. In addition they permit the answering of an important question concerning the difference between effects produced by double and single flickering lights. The disruption of depth perception by flickering lights does not appear to require the use of two lights. One flickering light appears to work as well as two.

The use of a single light would be much simpler to employ in a field situation because it would not require a complex communication system such as would be required for the phasing and regulating of multiple light sources. Of course the present result is based only on an objective performance measure. It could be that the apparent movement produced by double lights is subjectively more disturbing than is a single flickering light. Though post-experimental questionnaires did not show obvious evidence of this.

Both of these laboratory experiments indicate that flickering light does disrupt depth perception. However, the magnitude of increase in error under flicker (1 - 1 1/2 inches at 14 feet) may not be large enough to have any practical significance if flicker were used in the field as a harassment

TABLE IX

AVERAGE ERROR (IN QUARTER-INCHES) IN DEPTH PERCEPTION TASK UNDER DOUBLE vs SINGLE FLICKERING LIGHT

Away Light Position

Lights	Frequency (Cycles per Second) 6	9	Row Averages
Single	4.25	4.50	4.38
Double	5.25	5.43	5.34
Column Averages	4.75	4.96	4.86

Toward Light Position

Lights	Frequency (Cycles per Second) 6	9	Row Averages
Single	6.75	5.37	6.06
Double	5.18	6.81	6.00
Column Averages	5.98	6.09	6.03

Control - No Flicker

Prior to Treatment	After Treatment
2.43	3.14

Combined

2.79

TABLE X

SIGNIFICANCE TESTS FOR DATA IN TABLE IX

Comparison	Results
<u>Position</u> Toward or Away	$t = 1.53$, $p < .10$
<u>Frequency</u> 6 vs 9 cps	$t = .011$, NS
<u>Lights</u> Single vs Double	$t = .018$, NS
Control vs all Exp.	$F = 17.79$, $p < .01$

device. It is impossible to extrapolate from these results to the employment of these lights in the field, where the amount of increased error might be greater at longer distances.

The flicker frequency does not appear to be a critical variable within the range tested. It is already known from Experiment One that a higher frequency (12 cps) leads to better performance. Perhaps at frequencies lower than 6 cps, such as 4 and 2 cps, greater performance decrement would be found. This hypothesis is here suggested for further exploration.

EXPERIMENT FIVE

MANUAL DEXTERITY UNDER FLICKER, DOUBLE VERSUS SINGLE LIGHT

In Experiment Two a considerable decrement in manual dexterity was found under two alternately flickering lights. However, it was found in the studies of depth perception that a single flashing light was as effective as the double lights in disrupting performance. Accordingly, this experiment was designed to test the generalizability of this finding to manual dexterity performance. In other words, the question to be answered was this: "Was the performance decrement found in Experiment Two due specifically to the use of two lights, or could the same effect be obtained with a single light?" This question has the same practical implications discussed in Experiment Four. Because of the added difficulty of using two alternating lights on a large scale it must be shown that the use of two lights produce an added effect not obtainable with a single light.

METHOD

Fourteen subjects performed the Crawford Manual Dexterity Task three times. First they performed under regular room lighting as in Experiment Three. They were then given two trials under flickering light. One of these trials was under double and the other under single light. The order of the experimental treatments were counterbalanced between subjects. A three minute rest period was given between each three minute test trial. The procedure was exactly the same as that of Experiment Two with the addition of a third trial.

It was decided to hold frequency constant at 6 cps and intensity constant at a setting 2 on the Grass photic stimulators, as this was the stimulus combination producing most decrement in performance in the earlier experiment. Thus, the basic design was a 2 x 2, or order by number of lights design.

RESULTS

Difference scores were obtained between each subject's performance under the control condition and each of the experimental treatments. Again all scores were positive indicating a consistent decrement in performance under flickering light. The mean difference scores for each order by lights combination is presented in Table 11. These means are based on 7 scores in each cell. The corresponding analysis of variance is presented in Table 12.

By inspection of Table 11, it may be seen that the means are quite similar. The difference between treatment means was not significant. There is a slight trend for subjects to perform better on their second experimental trial, but this expected practice effect has no practical meaning.

The above analysis does not test the difference between flicker and control, although it does reveal that there was no difference between the

TABLE XI

MEAN DIFFERENCE SCORES BETWEEN CONTROL AND EXPERIMENTAL PERFORMANCE FOR EACH OF FOUR ORDER BY LIGHTS COMBINATION

Order of Presentation	Lights		Row Averages
	Double	Single	
1	15.86	16.29	16.08
2	14.57	15.00	14.79
Column Averages	15.22	15.65	15.43

TABLE XII

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE XI

Source	Degrees of Freedom	Mean Squares	F Ratio	Probability
Treatments	(1)	1.3	-	NS
Order	(1)	11.6	3.2	NS
Interaction	(1)	.61	-	NS
Error	(12)	19.9		
Nested Error	(12)	3.85		

two kinds of flicker. A t test for dependent measures between double flicker and control was highly significant ($t = 14.54$, $df = 12$, $p < .001$) as was a test between single flicker and control ($t = 16.36$, $df = 12$, $p < .001$).

DISCUSSION

As predicted from the results of Experiment Four a single flickering light was as effective as double flickering lights in producing decrement in manual dexterity. The present experiment casts further doubt on the original assumption that double flickering lights would produce an added performance decrement above what could be obtained with a single light.

At the frequencies investigated flickering light of any kind seems to be equally effective in disrupting the hand eye coordination involved in a manual dexterity task.

In addition to the performance data, subjects were asked for subjective reports as to which light condition bothered them the most. There were no decided preferences for either double or single flicker. These subjective reports are in agreement with the performance data.

EXPERIMENT SIX

A PSYCHOPHYSICAL STUDY OF OPTIMUM DOUBLE FLICKER FREQUENCY AND OF THE AMOUNT OF AMBIENT LIGHT REQUIRED TO ELIMINATE THE APPARENT MOVEMENT EFFECT OF DOUBLE FLICKERING LIGHTS

This experiment investigated the problem of optimum flicker frequency from a different approach. In earlier experiments flicker frequency was manipulated as an independent variable. In this experiment flicker frequency was the dependent variable. Subjects made phychophysical judgments in which they adjusted flicker frequency to achieve maximum apparent movement and visual disruption. The independent variables were (1) flicker intensity, (2) toward and away light position, and (3) ambient light, i.e., dark vs moonlight.

The introduction of the third variable above required the construction of an artificial moon in the ceiling of the experimental room (a 150 watt bulk above a 12 x 12 inch frosted glass window) which could be adjusted by means of a variac. It was felt that a possible artifact of the laboratory situation which limited generalization to a field situation was the fact that the flicker in the lab occurred in complete darkness while in the field there would always be some ambient light present. In this experiment we wanted to see if the parameters of flicker (frequency and intensity) would be different under dark vs moonlight conditions. It also seemed desirable to have the subject adjust the amount of ambient light in the room to a point where the flicker effect was eliminated. It was thought that this would give some indication of the problem that might be encountered in the field under bright moonlight. This later data was collected concurrently with the frequency data.

In addition to the above kinds of data, subjects also adjusted the frequency for upper and lower thresholds of apparent movement.

METHOD

Twenty subjects made three kinds of psychophysical judgments involving flicker frequency and ambient light under three levels of flicker intensity (2, 4, 8 setting on the Grass Photic Stimulators). Each subject was assigned to a given light position (toward or away) and ambient adjustment (descending or ascending) order and he made all of his judgments in that order. Order was counterbalanced between subjects.

Subjects were seated at one end of the experimental room at a table on which was placed the frequency control box, (which could be adjusted from 1 to 24 cps) and the variac for adjusting the ambient light on the target (which could be adjusted from 0 to 10.9 foot candles). A frequency meter which read in cps was also on the table and positioned so that the experimenter could read it using a flashlight when necessary.

The target was a 3 1/2 foot shop ladder made of a light colored wood. It was placed in the center of the room directly under the artificial moon.

All judgments were made with reference to the apparent movement of this target under flickering light.

In the "toward" light condition the lights were placed in each corner of the opposite side of the room with reference to the subject. They were aimed at the target and the light sources were visable to the subject. In the "away" condition the lights were placed on the subject's side of the room in the corners and focused on the target. The light sources were then about 2 feet behind the subject and not directly visable to him. This was the same positioning used in the depth perception experiments.

Because the procedural sequence is rather difficult to describe in general terms the sequence for subject number one is given as an example: This subject was run under the "toward" condition, meaning that he always worked with the lights positioned at the opposite end of the room. His particular order for intensity was 8, 4, and 2 and his ambient adjustment order was descending and then ascending. First he was instructed that we wanted to find out at which frequency he perceived the most apparent movement and visual disruption, and that he would be allowed to adjust the frequency until he found the point at which he perceived the most apparent disruption. For example, this subject's first intensity was 8. Therefore, the intensity was set at 8 (the moonlight was off) and the subject then adjusted the flicker frequency until he was satisfied that this was the frequency at which he perceived the most apparent movement and visual disruption. Then with the frequency remaining set at his own maximum point he adjusted the ambient, first descending until he found a threshold at which he began to perceive an apparent movement effect and then starting from no light he adjusted in an ascending direction until he lost the apparent movement effect. The intensity was then reset to intensity 4. Again frequency was adjusted to maximum visual disruption and then ambient light was adjusted again in descending and ascending order. The same thing was done for the third intensity condition.

At this time the ambient light was set on the variac at a voltage of 30 volts which was equal to .02 foot candles. This value is approximately equivalent to average moonlight. Then the subject adjusted the flicker frequency for each of the intensities (in the same order) again for maximum visual disruption.

The difference between this condition and the first was that ambient light was held constant (at moonlight value) and frequency was adjusted with the ambient light on. In the first condition frequency was adjusted without ambient light and then ambient light was adjusted for the threshold of apparent movement, i.e., point at which ambient light eliminated apparent movement.

The third time through his intensity order (8, 4 and 2) the subject was instructed that we wanted to know the upper and lower limits for the perception of apparent movement. The ambient light was off in this sequence. With light intensity set at 8 the experimenter adjusted the frequency control box to maximum output of around 24 cps. The subject then reduced the frequency rate to the point at which the target began to appear to move. The experimenter recorded this value and adjusted the control box to minimum

output of around 1 cps. The subject then increased the frequency rate to the point at which he ceased to perceive the light as flashing on and off of the target and the target itself began to appear to move.

The upper and lower thresholds of apparent movement were then taken at the other levels of intensity to complete the experiment. All combinations of position, intensity and order of adjustment were counterbalanced between subjects.

RESULTS

The frequency data were recorded in terms of total flashes per second from both lights. Prior to the running of the experiment, accurate measures of ambient light on the target (in foot candles) had been obtained corresponding to the various voltage settings on the variac. The raw data were collected in terms of voltage settings on the variac. These data were transformed into foot candle values for use in the data analysis.

Consider first the frequency data. These data are presented in Table 13. The means in this table are based on 10 observations per cell, as half of the subjects performed in the "toward" and the other half in the "away" condition. It may be seen that the differences between means for the various treatment combinations are quite small. None of the means depart from the grand mean (7.9) by as much as 1 cps. The data in Table 13 were analyzed by analysis of variance and nothing was significant. From this result it appears that the average flicker frequency at which apparent movement is maximized is around 8 cps (7.9 = grand mean) and that this is not significantly altered by the direction or intensity of the lights nor by a quantity of ambient light equivalent to average moonlight. The wide variability (S.D. = 2.26) of judgments should also be noted. This means that, while the mean frequency was around 8, a range of from 3.5 to 12.5 cps would be required to include 95 percent of the observations.

Table 14 presents the mean amount of ambient light in foot candles required to "wash out" the flicker effect for both ascending and descending adjustments. It may be seen that there is a great difference between the average ascending and descending values. This result was not expected and there is no obvious explanation for it. However, this difference was consistent for all subjects. It seems that two different thresholds were measured by the two procedures and it is meaningless to average these values. There seems to be a trend in the ascending condition for amount of ambient light to be related to intensity. This relationship approached significance ($F = 3.17$, $df = 2, 57$, $p < .08$). It was not significant when descending adjustments were made.

The third part of this experiment measured upper and lower frequency thresholds for apparent movement under three intensity levels. Table 15 presents these means. It may be seen that the average lower threshold is around 4.3 while the average upper threshold is around 17 cps. The variability in these data is not as great as in the adjustment for optimum movement. Most subjects begin to perceive apparent movement between 20 and 15 cps and they cease perceiving it at between 5 and 3.5 cps.

TABLE XIII

OPTIMUM FLICKER FREQUENCY FOR APPARENT MOVEMENT UNDER VARYING LIGHT POSITIONS, INTENSITIES AND AMOUNT OF AMBIENT LIGHT

Toward-Light Position

Ambient Light	Light Intensity (Instrument Settings)			Row Averages
	I_2	I_4	I_6	
Dark	7.6	8.3	8.7	8.2
Moonlight	8.5	7.9	8.1	8.18
Column Averages	8.05	8.1	8.4	8.19

Away-Light Position

Ambient Light	Light Intensity (Instrument Settings)			Row Averages
	I_2	I_4	I_8	
Dark	7.2	7.9	7.7	7.6
Moonlight	7.2	8.0	7.7	7.6
Column Averages	7.2	7.95	7.7	7.6

Grand Mean = 7.9
Standard Deviation = 2.26

TABLE XIV

AMOUNT OF AMBIENT LIGHT REQUIRED TO ELIMINATE THE APPARENT MOVEMENT EFFECT AT DIFFERENT LIGHT INTENSITIES FOR ASCENDING AND DESCENDING ORDER OF ADJUSTMENT

Series	Light Intensity (Instrument Settings)		
	I_2	I_4	I_8
Ascending	1.19*	1.69	2.20
Descending	.22	.23	.36

*foot candles

TABLE XV

MEAN UPPER AND LOWER THRESHOLDS OF APPARENT MOVEMENT AT VARIOUS LIGHT INTENSITY VALUES

Threshold	Light Intensity (Instrument Settings)			Row Averages
	I_2	I_4	I_8	
Upper Threshold	16.0*	17.05	18.08	17.04
Lower Threshold	4.16	4.4	4.4	4.32

*cps

DISCUSSION

The finding of wide individual differences in perception of optimum flicker frequency is somewhat problematic when considering the use of flicker as a tactic. Apparently no one frequency will be best for use with all individuals, some may be more affected by 6 cps while others are more affected by 9 cps. This could possibly be related to visual acuity among other things.

The fact that such wide differences were found between ascending and descending judgments of ambient light thresholds for apparent movement is also problematic. Some of this result may have been due to differences in dark adaption. When subjects started with a good deal of ambient light (descending order) they were not dark adapted. However, starting with no ambient light (ascending order) they may have dark adapted to some extent while the equipment was being prepared for the next trial.

There is no real practical problem posed by the difference between ascending and descending order. The question for which an answer was being sought was whether moonlight could be expected to wash out the flicker effect in the field. Even if we take the data from the descending order, the answer to the question seems to be that moonlight would not destroy the apparent movement effect. Moonlight is reported to be around two hundredths of a foot candle. Yet it required values of ambient light 11 times that great to eliminate even low intensity flicker. However, while the flicker effect (apparent movement) was still present with ambient light, it was observed that objects in the environment could be seen better when some ambient light was present. Further experiments should assess performance rather than the perception of flicker with ambient light present.

The data on upper and lower thresholds for apparent movement under flicker indicates that for most subjects the effect is not present at values of 4 cps or below. What occurs at slow rates of flicker is an on-off effect but not apparent movement of objects in the environment. Based upon observations in this experiment it was decided that these slower rates of flicker might be more disturbing than the faster rates which produce apparent movement effects. It was decided to explore slower flicker rates in subsequent experiments.

EXPERIMENT SEVEN

VIGILANCE UNDER SLOW FLICKER

In line with previous results which suggested that the slower flash rate (6 cps) was producing more performance decrement it was decided to study the effects of 4 cps flicker. In pilot studies using an electroencephalograph more disruption of brain wave patterns was also found at 4 cps.

During the course of experimenting with the flicker equipment a method was invented for producing another kind of flicker. Previous research had been conducted with either a single flashing light or two lights flashing alternately. Under this new concept a device was built whereby two lights could be used but the alternation between lights could be varied to occur after 2-10 flashes. In other words, one light would flash several times and then the second light would flash several times. When the light sources were placed on opposite sides of the room a flicker effect was produced that was quite different from that which had been previously observed. At faster flash rates (18-24 cps) alternating lights, or every second or third flash, produced a strange kind of apparent movement. This was similar to the apparent movement observed previously under the double lights at about 7-9 cps, but the effect seemed to be enhanced by the faster flicker rate which was superimposed on the alternation rate. At slower flash rates (2 on one light and then 2 on the second for a total of 4 cps) visual disorientation seemed to be enhanced. In the present experiment this latter was compared to double flicker of 4 cps alternating on every flash.

A device was also developed for fluttering a sound stimulus at various rates. In the present experiment a third experimental condition consisted of an 11 kc pure tone (at 80 db) fluttered at 4 cps plus the 2 + 2 flickering light condition.

One problem that had arisen was the measurement of the subjective effects of flicker and flutter. It was decided to use the Nowlis Adjective check list of mood post experimentally as a quantitative measure of subjective effects. The third experimental condition was added in an attempt to create the most subjectively unpleasant situation available. This was viewed mainly as a pilot test of the sensitivity of the mood check list to differences in subjective effects between treatment conditions.

In the previous experiments the duration of continuous exposure to flicker had been brief (3 to 5 minutes without rest). It was thought that perhaps the effects of flicker would be cumulative over a longer period of continuous exposure. Therefore subjects were exposed to 20 minutes of continuous flicker in the present study.

Previous studies of flicker had shown deleterious effects of flicker for depth perception and motor performance. It was thought that vigilance behavior over time would give another indication of the effects of flicker not tapped by the other measures. It was decided to use a disjunctive reaction time task presented several times over a 20 minute time interval as the vigilance task.

METHOD

Four groups of 5 subjects each were given a disjunctive reaction task over a 20 minute period. Subjects were run individually.

A standard reaction time apparatus was used. Either a red or a green light of equal brightness was presented and the subject's task was to turn off the light by pressing one of two buttons. The stimulus was presented 12 times at predetermined intervals within the 20 minutes time period (6 times for each color).

Subjects were seated at a table, holding the respond button, on one side of the experimental room. The stimulus box was placed directly in front of the subject and across the width of the room at a distance of 13 feet. The lights were placed on a line with the stimulus box and were 19 feet apart. The lights were each approximately 17 feet from the subject. This represented a wider distance between lights than had been used in previous experiments. This wide spread of the lights was used to allow the subject to clearly see the stimulus so that any effect obtained could be attributed to vigilance rather than to any blinding effect of the light. Light brightness was held constant at a setting of 8 for all flicker conditions.

The four treatment conditions were as follows: (1) control group (N = 5), who performed the task in artificial moonlight without flicker; (2) a group (N = 5) who performed the task under double flickering light at 4 cps with lights alternating on each flash; (3) a group (N = 5) who performed the task under 2 + 2 = 4 cps flickering light with lights alternating after each second flash; (4) a group (N = 5) who received the same light condition as in number 3 above with the addition of an 11 kc (at 80 db) tone which fluttered at a rate of 4 cps.

Subjects were instructed as to the nature of the task and given two practice trials (one for each stimulus color-button combination) before the experiment was begun. They were not told the length of time that they would be exposed to flicker nor the number of times that the stimulus would be presented.

Immediately after the completion of the experiment subjects were measured on two kinds of subjective reports. On one they were given a 9 point scale of times from none to indefinitely and asked to check the amount of additional time that they would be willing to be exposed to the lights (or lights and sound). The other was the Nowlis adjective check list of mood which took about 20 minutes to complete.

RESULTS

Raw data were recorded in hundredths of a second. To assess the cumulative effects of time of exposure, reaction times for each subject were averaged separately for the first 6 and the last 6 trials. This method of scoring was thought to yield a more stable index of performance than would have been given by the raw scores over 12 trials.

Table 16 presents the mean reaction times in hundredths of a second for each of the 4 experimental groups for the first and last halves of the 20 minute period. These scores were multiplied by 100 and submitted to an analysis of variance, the results of which are summarized in Table 17. It may be seen that neither of the main effects are significant. However, there are empirical differences between groups which may have been significant had the sample size been larger. The interaction, however, is significant ($F = 4.52$, $p < .05$). By inspection of Table 16 it may be seen that the control group does not contribute to this interaction as the means for the first and second halves are about equal. The interaction is due to differential effects between the flicker conditions (4 vs 2 + 2). It appears that the 4 cps flicker does not initially produce as much performance decrement, but its effects are more deleterious over time. On the other hand, the 2 + 2 conditions produced initial performance decrement but subjects were able to adjust to this over time. The fact that this result occurred in both 2 + 2 conditions shows the stability of this latter trend.

It is interesting to note that sound seemed to enhance vigilance performance rather than to disrupt it. These differences were not statistically reliable, but are suggestive for further research. It was certainly not expected that such a result would occur.

Table 18 reports the mean amount of time of reported willingness to remain in the experimental room (measured on a 9 point scale of (1) none, (2) 15 minutes, (3) 30 minutes, (4) 1 hour, (5) 2 hours, (6) 4 hours, (7) 8 hours, (8) 12 hours and (9) indefinitely). These time estimates were assigned numbers from 1 to 9 on the assumption that this scale was subjectively linear and these values were then submitted to an analysis of variance. This analysis is presented in Table 19. It may be seen that the control group is significantly different ($F = 6.11$, $p < .05$) from the experimental groups. The experimental groups do not differ. It is interesting to note that these results parallel the vigilance performance data. On the average subjects in the 2 + 2 plus sound condition were willing to stay under stimulation a little longer. They also performed a little better than did subjects in the other two experimental conditions.

The Nowlis mood check lists were scored over all and for the various sub-scales. This instrument did not distinguish between the control and the experimental groups. Consequently, that data will not be further discussed.

DISCUSSION

Again, as in the earlier studies, flicker was found to produce a performance decrement. Due to the limited number of subjects available it was not possible to include flicker frequency rates comparable to those used previously with other dependent measures. Unfortunately, this limits the comparability of the present data to previous results.

The data suggests that different kinds of flicker may have different effects over time. This suggests further research concerning performance under flicker over time.

TABLE XVI

MEAN REACTION TIMES OF THE FOUR GROUPS (IN 1/100 SEC) FOR THE FIRST AND LAST HALVES OF THE EXPOSURE TIME

Group	Time of Exposure		Row Averages
	1st Half	2nd Half	
Control	.67	.69	.68
4 cps	.76	.98	.87
2 + 2	.99	.79	.89
2 + 2 plus sound	.84	.72	.78
Column Averages	.82	.80	.81

TABLE XVII

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE XVI

Source	Degrees of Freedom	Mean Squares	F Ratios	Probability
Groups	(3)	928.3	NS	
Time	(1)	49.	NS	
Interaction	(3)	1350.	4.52	$p < .05$
Error	(16)	987.		
Nested Error	(16)	298.6		

TABLE XVIII

AVERAGE LENGTH OF ADDITIONAL TIME THAT SUBJECTS WOULD BE WILLING TO REMAIN IN THE VARIOUS ENVIRONMENTS

Group		Scale Value	Hours
Control	=	7	8 hours
4 cps Flicker	=	3.8	55 minutes
2 + 2 cps Flicker	=	3.8	55 minutes
2 + 2 cps plus Sound	=	4.4	1 hr. 20 min.

TABLE XIX

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE XVIII

Source	Degrees of Freedom	Mean Squares	F Ratios	Probability
Groups	(3)	11.67	2.10	NS
Error	(16)	5.56		
Contrast				
Control vs Experimental	(1)	34.0	6.11	$p < .05$

Concerning the finding of better performance under sound than without it is very suggestive. In retrospect, an experimental condition which used fluttering sound alone should have been included so that a more precise evaluation of its effect could have been made. The experimenters felt that the fluttering sound was unpleasant to the extent that they wore ear plugs while conducting the experiment. It is not clear as to why better, rather than worse, performance and subjective reports were observed under this condition. However, this is consistent with some pilot research using the manual dexterity task and an arithmetic problem solving task. Using these tasks there was no performance decrements under unpleasant sounds.

EXPERIMENT EIGHT

COGNITIVE-MOTOR PERFORMANCE UNDER FLICKERING LIGHT IN A DARK ROOM VERSUS FLICKERING LIGHT IN ARTIFICIAL MOONLIGHT

During the course of the research program it became increasingly clear that the use of a laboratory dark room might not be comparable to conditions where some ambient light (moonlight) might be present. The purpose of this experiment was to see if performance decrements obtained under flicker would be attenuated by ambient light.

This experiment continues the investigation of low flicker frequencies under conditions of alternating lights after every flash (regular) and alternating lights after every other flash (split). It corrects one of the defects in Experiment Seven by using a 6 cps flash rate in one condition for comparability to earlier experiments.

The Minnesota Spatial Relations Form Board (Forms A and B) was selected as a task. This task combines both intellectual functioning and motor coordination under time pressure. As such it was thought to be an adequate task for assessment of the effects of flicker. It was expected that a large practice effect would be obtained over the 10 repeated measures, but that this could be controlled for in the analysis.

In previous studies some female subjects were used, but their numbers were not sufficient to allow for the testing of sex differences in the analysis. In the present study enough female subjects were tested to allow for a testing for sex differences.

The present experiment also utilized a larger sample of subjects within groups than was used in the earlier studies.

METHOD

Thirty-six subjects (24 male and 12 female) performed the Minnesota Spatial Relations Form Board task 10 times within a 70 minute experimental session. They alternated Form A and Form B so that each form was given 5 times. Subjects were run individually.

The experimental design was 2 x 3 x 3 x 2, or sex (male and female) x condition (tested sequentially under ambient, flicker and room light) x flicker frequency (6, 2 + 2 and 2 cps) and light during flicker (dark and ambient artificial moonlight of .02 foot candles). Replications were nested in conditions and crossed with all other variables. Intensity of the strobe lights was held constant at a setting of 2.

Subjects were instructed as to the nature of the Form Board task. The board was approximately 14 x 36 inches in size and contained approximately 50 cut out blocks of various geometric shapes. Subjects started with all of the blocks out of the board and covered by a cardboard. When the signal was given they were to correctly place the blocks in the board as rapidly

as possible. A 6 minute fixed interval was given between the starting of each trial. So that a subject who completed the task in 3 minutes, then rested for 3 minutes before beginning the next trial, etc. Timing was done with a stop watch.

All subjects were first given 4 trials under regular room light. The first 2 trials were given to eliminate the bulk of the practice effect before actual measurement was begun. The average of the third and fourth trials was to be used as a base line against which to compare performance under the various light conditions. It was assumed that there would be some practice effect after the fourth trial, however, this would work against the hypotheses of performance decrement under the light conditions.

After the fourth trial the room lights were turned off and the ambient or artificial moonlight was turned on. All subjects were given 5 minutes in which to dark adapt under the ambient light. Then they were given trials 5 and 6 under ambient light without flicker. Subjects who were to receive flicker under ambient light were then given 10 more minutes of dark adaption under the ambient light. Subjects who were to receive flicker in the dark were given 10 minutes dark adaption with no ambient light present. Then subjects were given trials 7 and 8 under one of the 3 flicker frequencies under the background light condition for which they had been adapted. The room lights were then turned on and all subjects adapted to the light for 3 minutes before being given trials 9 and 10.

RESULTS

Raw data were recorded in total time in seconds to complete each trial. For purposes of analysis trials 3 and 4 were summed and this score was used as a base line. The other pairs of trials, 5 and 6 (ambient), 7 and 8 (flicker), and 9 and 10 (room light) were then subtracted from the base line. Thus, performance decrement was indicated by a minus number. Table 20 presents the mean performance scores thus obtained. The corresponding analysis of variance is presented in Table 21. Since some of the cell frequencies were unequal the method of unweighted means was used.

Inspection of the means in Table 20 shows that there was some practice effect between trials 3 and 4 and 9 and 10. However, there were consistently large performance decrements under ambient moonlight without flicker as well as under flicker. A contrast between ambient and flicker revealed that there was no significant difference between them. The highly significant condition effect ($F = 20.80$, $p < .001$) was due to better performance under last room light and the other two conditions rather than to any difference between flicker and moonlight.

Sex of subjects also led to highly significant differences ($F = 11.28$, $p < .01$). Females generally performed worse under all other conditions than did males. The sex x frequency interaction is also significant ($F = 5.23$, $p < .01$), indicating that females in the 2 + 2 condition did about as well as males while they did much more poorly under 6 and 2 cps flicker.

The background light under which flicker is presented also led to a significant difference ($F = 7.09$, $p < .05$). Thus, subjects do worse under

TABLE XX

MEAN PERFORMANCE DIFFERENCE SCORES IN SECONDS FOR THE VARIOUS GROUPS IN EXPERIMENT EIGHT

Light During Flicker

Frequency: 6 cps

	Dark: Ambient	Dark: Flicker	Dark: Room light	Ambient: Ambient	Ambient: Flicker	Ambient: Room light
Males	-86	-64	22	-60	-40	13
Females	-101	-115	11	-116	-85	18

Condition

Frequency: 2 + 2 cps

	Dark: Ambient	Dark: Flicker	Dark: Room light	Ambient: Ambient	Ambient: Flicker	Ambient: Room light
Males	-87	-134	25	-104	-56	20
Females	-76	-92	21	-109	-63	4

Frequency: 2 cps

	Dark: Ambient	Dark: Flicker	Dark: Room light	Ambient: Ambient	Ambient: Flicker	Ambient: Room light
Males	-115	-144	48	-94	-38	23
Females	-150	-212	8	-104	-75	15

TABLE XXI

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE XX

Source	Degrees of Freedom	Mean Squares*	F Ratios	Probability
Sex	(1)	8,028.	11.28	$p < .01$
Condition	(2)	138,524.	20.80	$p < .001$
Frequency	(2)	319.	-	NS
Light	(1)	5,048.	7.09	$p < .05$
Sex x Condition	(2)	861.	-	NS
Sex x Frequency	(2)	3,722.	5.23	$p < .01$
Freq. x Condition	(4)	2,286.	-	NS
Sex x Light	(1)	1,013.	1.42	NS
Freq. x Light	(2)	7,579.	10.65	$p < .01$
Light x Condition	(2)	18,337.	2.75	NS
Error	(42)	712.		
Nested Error	(30)	6,656.		

*Corrected for unequal cell frequencies by use of the harmonic mean.

flicker against a background of dark than against a moonlight background. This finding, along with the finding of no difference between flicker and ambient, seems to confirm earlier suspicions that flicker effects produced in the laboratory might not generalize to field conditions. The frequency x light (background) interaction was also significant ($F = 10.65$, $p < .01$). This stems mainly from the 2 cps group where performance decrement was twice as great in the dark as in the moonlight. This was also the condition under which the least amount of illumination was present.

DISCUSSION

This experiment represents the most sophisticated design thus far. Taken in the context of the previous studies it permits evaluation of some important questions. In this experiment 6 cps was found to lead to the best performance. In previous experiments where 6 cps was the lowest frequency it led to the worst performance. From this performance decrement under flicker it can be conceptually visualized as an increasing function as the frequency of the flicker becomes lower. Also when some ambient background light is present performance increases. In other words, any task involving visual performance seems to be a function of the amount of light present regardless of whether that light is flickering or not. Flicker does not seem to add any performance decrement above and beyond what would be observed of a subject working on a visual task in darkness or in moonlight.

Of course, flicker might have subjective effects or cumulative effects which would still justify its use as a harassment tactic. However, such profound psychological effects were not apparent from the crude measures of them that were used in the present series of studies. It seems if flicker produces profound psychological feelings of unpleasantness that this effect should have been picked up by our post experimental interviews. For a further study it is suggested that subjective reports be asked for periodically during prolonged exposure to flicker rather than at the end of the experiment. Exposure to longer periods of flicker may produce effects in performance and subjective state of well being not observed during the 12 minutes of continuous flicker employed in the present study.

The finding that females show more and different performance decrement under flicker than do males suggests that females should not be used as subjects in further studies. Particularly, if generalizations are to be made to a military population.

EXPERIMENT NINE

COGNITIVE-MOTOR PERFORMANCE UNDER EXTENDED EXPOSURE TO FLICKER COMBINATIONS OF SPLIT OR REGULAR AND 4 OR 6 cps

This experiment continues the investigation of performance on the Minnesota Spatial Relations Form Board begun in Experiment Eight. It was thought desirable to investigate the effects of longer exposures to flicker than had previously been used. Consequently, subjects in this experiment spent one hour under flicker, during which they were measured several times. Also, subjects were run in pairs in order to more fully utilize the time involved in conducting the study and to keep motivation high by inducing a sense of competition.

In the previous study an interaction was found between flicker frequency and light conditions of ambient vs dark. Subjects under the split flicker (2 + 2) condition had equal performance decrement under both ambient and dark light conditions. In the two regular flicker conditions (2 and 6 cps) performance was better when ambient background light was present. In that experiment, which was designed to explore a range of flickers, the split flicker was confounded with its frequency. It was impossible to determine whether the decrement in ambient light occurred because of the flicker being "split" (i.e. 2 + 2) or because the frequency of 4 cps was critical. The present experiment was designed to test two flicker frequencies (4 and 6 cps) and two kinds of flicker (regular and split).

Finally, this experiment utilizes the largest sample of subjects thus far. Also, only male subjects were used in accordance with the sex difference found in the previous study.

METHOD

Forty male subjects were assigned to one of 4 experimental conditions. The design was 2 x 2 x 5 with the third variable representing repeated measures over time. The variables manipulated were frequency of flicker (4 vs 6 cps) and whether the lights flashed alternately (regular) or successively (split). Light intensity was held constant at a setting of 2.

Testing took place over a two hour time period and subjects were run in pairs. One subject within a session was assigned to form A of the Minnesota Form Board and the other to form B. They did not alternate forms between trials. Form order was counterbalanced between sessions and light conditions.

A total of 8 trials were given to each subject during the course of the two hour session. The first 3 and the last were under ambient or moonlight, and trials 4 through 7 were under flickering light. Trial 1 was a practice trial and trials 2 and 3 were base line trials for comparison to the last 5 trials.

During the initial 5 minutes in the experimental room, subjects were

allowed to become dark adapted under the ambient light of approximate moonlight value (.02 foot candles on the task). They were instructed as to the nature of the task.

Following dark adaptation the first subject was asked to come forward to the table on which the form board lay with the forms in front of it covered from his vision by a cardboard. He was instructed to begin at the sound of a bell at which time a stop watch was activated.

Subjects performed in 7 minute intervals. That is, it may have taken the first subject 5 to 6 minutes to complete the task. The second subject did not start until 7 minutes from the first subject's start had elapsed, etc. When the flicker was turned on after the completion of the third trial an additional 3 minutes was given before the first subject began. The ambient light remained on during the flicker. Under the flickering light condition the subjects performed 4 times each. At the end of these trials the flickering lights were turned off and 3 minutes dark adaption time was given before subject 1 began his final trial under ambient light. The subjects worked under ambient light for a total of 61 minutes and under flicker for exactly 59 minutes.

After completion of each trial, subjects were asked to report how they felt. At the end of the experiment they also completed the Nowlis Mood check list.

RESULTS

Performance scores (in seconds) for each of trials 4 through 8 were subtracted from the average of the 2 base line trials (2 and 3). Table 22 presents the resulting mean performance difference scores for the 2 x 2 x 5 design. Positive scores mean better performance on the test trials than on the base line trials. Thus, in every case average performance under flicker was better than under the ambient base line. This better performance is probably due to practice effect, but had the flicker had much effect performance decrement should have been obtained.

Table 23 presents the analysis of variance for the data in Table 22. Only two factors were significant. The measures effect was highly significant ($F = 90.82$, $p < .001$) indicating only that subjects improved with practice. The greater strength of the practice effect in the present experiment is probably due to the fact that no practice under room light was given. The other significant effect was the 3-way interaction ($F = 5.48$, $p < .05$). This interaction was broken down into simple effects in an attempt to determine if there was a significant difference between measures for the 4 experimental combinations. However, no significant differences were found.

On the assumption that split flicker would be more detrimental than regular flicker, a contrast was performed. There was no significant difference found ($F = 1.32$, df 1, 80).

Concerning the subjective reports, most subjects continued to report "I feel good", "fine", "O.K.", "the same", etc. after almost an hour under

TABLE XXII

MEAN PERFORMANCE DIFFERENCE SCORES (IN SECONDS) FOR THE VARIOUS FLICKER CONDITIONS OVER 4 TRIALS AND THE FINAL CONTROL TRIAL (TRIAL 8)

Condition	Trials				
	4	5	6	7	8
4 cps - Regular	22	39	43	48	53
6 cps - Regular	13	31	36	49	54
4 cps - Split (2 + 2)	6	38	45	52	70
6 cps - Split (2 + 2 + 2)	8	15	35	33	40

TABLE XXIII

ANALYSIS OF VARIANCE FOR THE DATA IN TABLE XXII

Source	Degrees of Freedom	Mean Squares	F Ratios	Probability
Flicker	(1)	1,501.5	.35	NS
Frequency	(1)	4,880.7	1.15	NS
Measures	(4)	9,845.3	90.82	$p < .001$
Flicker x Frequency	(1)	1,658.9	.39	NS
Flicker x Measures	(4)	255.7	2.36	NS
Frequency x Measures	(4)	213.9	1.97	NS
3-way Interaction	(4)	594.3	5.48	$p < .05$
Error within Blocks	(16)	4,223.9		
Nested Error	(64)	108.4		

flicker. A few reported minor symptoms such as "eye-strain", "tired", "a littly dizzy", "a little unbalanced", "a little edgy", etc. None of these symptoms persisted after the cessation of flicker. The Nowlis Mood check list did not differentiate between high and low performers.

DISCUSSION

As in the previous experiment comparing ambient light of low intensities to flickering light no differences were found. In fact, giving a subject a light to see by even though it is a flickering light may leave him better off from the standpoint of certain performances requiring vision than leaving him in the moonlight. When the fallacy of using optimum lighting conditions (room light) as a base is eliminated in favor of a more realistic base line of performance in moonlight, flicker as employed in these studies does not seem to increase performance decrement.

One idea suggested by these experiments is the use of a very bright light which would flash at irregular intervals of several seconds. Under these conditions dark adaption might be kept continually at a minimum and consequently performance might be less than when the subject is dark adapted in the moonlight.

EXPERIMENT TEN

WORK WITH AUDITORY FLUTTER

Considerable time was expended during the course of the research effort to investigate the effects of auditory flutter on human performance. Certain unforeseen and unavoidable difficulties with the sound equipment precluded a full scale experimental program. It was intended to investigate sound frequency, flutter rate (number of sound pulses per second) and sound intensity in much the same manner that flickering light was studied, and then later to combine flicker and flutter in the same experiments. Some pilot subjects were run as a first step in this direction. While the sound seemed to the experimenters to be somewhat unpleasant, a dependent measure of either a cognitive or a performance nature was not found which showed promise of being adversely effected by the sound environment at intensities below 100 db. For example, a few subjects worked arithmetic problems under time pressure in the sound environment with no apparent decrement in performance. Other subjects performed the manual dexterity task with the same results. In the one experiment where sound was introduced along with the lights, an increment rather than a decrement in performance was obtained.

Initially, it was impossible to do more than informally run pilot subjects with the sound because equipment was not available for accurately measuring the sound intensity in the experimental room. The experimenters felt that subjecting subjects and experimenters to high frequency tones of undetermined (but high) intensities was unwise and could result in damage to the ears. Several weeks elapsed before equipment was made available which measured intensity accurately at the required frequencies. During this time one of the speakers ceased to function resulting in further delay.

Electronic devices were built for the purpose of fluttering the sound at variable rates. The first effort at this failed because it would not produce a flutter effect at intensities higher than 65 db. A second device was built and it was used in the vigilance experiment.

One small experiment ($N = 11$) was conducted which was concerned with the ease of locating a sound source at high (11 kc) and low (1 kc) frequencies at two levels of intensity (60 and 80 db). It was found that blindfolded subjects could not locate the sound source as well for high frequency sound as they could for low. An interaction was also found. At the low frequency the high intensity tone was more easily located while at the high frequency the high intensity was most difficult to locate. This experiment used continuous tones rather than fluttering ones.

Based on these preliminary observations it was the opinion of the experimenters that either fluttering or continuous tones, while being somewhat unpleasant, would not be an effective psychological weapon at the intensities investigated.

SECTION III

CONCLUSIONS AND RECOMMENDATIONS

1. Two lights flickering out of phase, at frequencies below critical flicker fusion frequency, produce performance decrements of various magnitudes when compared to performance under normal room lighting. In general, this performance decrement is increased at lower flicker rates. This suggests that the performance decrement observed is due to interference with visual processes, while measuring performance on a visual task, rather than interference with consciousness and cognition.

2. Two lights flickering out of phase did not produce any more performance decrement than that which could be obtained using a single light flickering at the same frequency. This casts serious doubt on the practical utility of the double lights as a harassment device. A single light seems to work as well. It also suggests that the performance decrement that is obtained is not due to the peculiar apparent movement effect of the double lights, but to the lack of proper illumination.

3. A few individuals report mild somatic symptoms such as dizziness, nausea and headaches under flicker. These symptoms do not seem to be serious enough nor wide spread enough to justify the use of flickering lights, such as those employed in the present experiments, with the aim of producing somatic symptoms.

4. There was little evidence of anxiety, interference with consciousness or other profound psychological effects under flicker. Although most subjects described the effects of the lights as mildly unpleasant.

5. The use of a pitch black experimental room was found to be somewhat unrealistic. The perception of apparent movement with artificial moonlight present was not affected, however, performance decrement was somewhat attenuated by the presence of artificial moonlight. This finding limits the possible utility of flickering lights in a field situation.

6. When performance under flicker was compared to performance on a visual task for dark adapted subjects in moonlight the flicker did not add any performance decrement. Thus, while flicker reduces efficiency when compared to optimum lighting it might not have any added effect when employed against an individual already in the dark. This latter comparison seems to be the critical one in evaluating the utility of flicker as a weapons tactic.

7. It is here suggested that a very bright light flashed irregularly at intervals of several seconds might have more utility as a weapon. Such a light could destroy dark adaptation and thus render an individual less able to perform than he was in a dark adapted state. Within the limited time period of the present program it was not possible to investigate this.

8. No firm conclusions can be drawn from the present observations of the effects of auditory flutter. However, it was the opinion of the experimenters that at the intensities and brief exposure times observed, auditory

flutter did not show promise as a harassment device. At intensities high enough to produce pain (130 db) or over longer durations fluttering sounds might be very effective.

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13 ABSTRACT Results of nine laboratory experiments conducted under contract AF 08 (635) 5256, entitled "Study of Effects of Visual Flicker and Auditory Flutter on Human Performance", are contained in this report. The purpose of the research was to assess the feasibility of using dual source flickering lights and fluttering tones as harassment devices or as non-lethal weapons. Performance was measured on depth perception, manual dexterity, aiming and tracking, vigilance and a cognitive-motor task. Psychophysical judgments of the apparent movement effect produced by two lights flickering out of phase were obtained in one experiment. Postexperimental interviews were given to assess the psychological and somatic symptoms associated with exposure to flicker and flutter. While dual source flickering lights produce performance decrement from optimum conditions, they are no more effective than a single light. Compared to performance under artificial moonlight flickering lights do not add to performance decrement. A few minor psychological and somatic complaints under flicker were reported. These were neither serious enough nor wide spread enough to justify the use of flickering light as a weapon. Little quantitative data was obtained with regard to fluttering tones, however, informal observation led to the conclusion that flutter did not show promise as a harassment device at the intensities investigated.

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